Simulation Study of Borda's Profile & Parallel Plane Electrode to Assess Electric Field Uniformity

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***Abstract*-The electrode gaps which results in to uniform electric fields are the most widely used gap configurations in assessing dielectric strength. In the present study simulation results of two electrode gap configurations namely, parallel plane profile and Borda's profile are reported. The Charge Simulation Method (CSM) is used to compute electric fields with errors in simulation being less than 0.04% (in potential). In order to assess the uniformity in electric field in the gap, numerical experiments are conducted by varying parameters like gap spacing, overall radius. Computed electric fields on the surface of the electrode help in comparing non-uniformity in electric fields for the two electrode configurations.**

Simulation results indicate that for the same overall dimension of the electrode and the gap spacing, parallel plane electrode gives lower non-uniformity factor when compared to the Borda's profile. But the advantage with the Borda's profile is that the maximum field on the electrode occurs at the edge of the electrode, which is away from the region of interest. Where as the maximum field in case of a plane electrode occurs at the edge of the linear portion of plane profile. Also looking at the field distribution along the gap axis indicate that Borda's profile yields more uniform fields.

INTRODUCTION

The uniform field electrode configurations are of significance in basic research, testing, and characterization of insulating materials. Theoretically, the uniform field intensity is produced within the space limited between the two parallel plane electrodes of infinite dimensions. In practice since the electrode dimension cannot be infinite, carefully designed electrodes are necessary to produce uniform fields in the region of interest and to assure lower field intensities at all other points in the test gaps. Different electrode configurations like simple plane profile, Rogowski and Bruce profiles have been used in producing uniform fields [1]. Rapid developments in digital computation techniques however have made assessing and designing newer configurations. Such an earlier effort using finite difference technique is by Harrison [2]. Harrison in his work placed emphasis on the uniformity of field along the gap axis. In many a situations like stressed volume theory and related studies of insulating materials electrode area, volume of the sample stressed become important. Hence uniformity of the field along the electrode surface has also become significant. In light of this newer designs have been attempted [3]. A relatively newer profile, namely, Borda's profile and field optimizations by CSM are attempted and reported by H Okubo et al [4].

The CSM [5,6] being one of the most widely used method for numerical field computation for open geometry fields are suitable for studying electrode configurations of this kind. In the present work CSM is used to simulate and evaluate the electrode configurations. Some of the results available in the literature for the geometry's studied are examined to ascertain the efficacy of the simulation model.

Though it is easier to compute numerically the profiles suitable to yield uniform fields but it takes effort to fabricate these complicated profiles and realize its application in experimentation. Hence this has been an effort to have a re-look at the simple geometry like parallel plane geometry and compare its performance with the Borda's profile from the point of field uniformity.

SIMULATION METHOD

The charge simulation method [5,6] is an integral equation technique which makes use of mathematical linearity and expresses the Laplaces equation as a summation of particular solution due to set of known discrete fictitious charges. In effect the field formed by a number of charges (equivalent) simulates the actual E-field due to the charges present on the electrode, which are placed outside the region where the field solution is desired. By properly locating the charges, their magnitudes are found by satisfying the boundary condition at the selected number of counter points on the boundaries. On knowing these charges the potential and electric field intensity at any point can be determined from the combined effect of these charges. The resulting simulation accuracy depends strongly on the choices concerning type of simulating charges, the location of charges, counter points. It has been suggested that potential error values below 0.1% are reasonably acceptable [5].

In the present work the electrodes are simulated using ring charges and the typical error plot of potential on the electrode surface is shown in figure 1. The infinite ground plane electrode is simulated using image electrode with image charges on it.

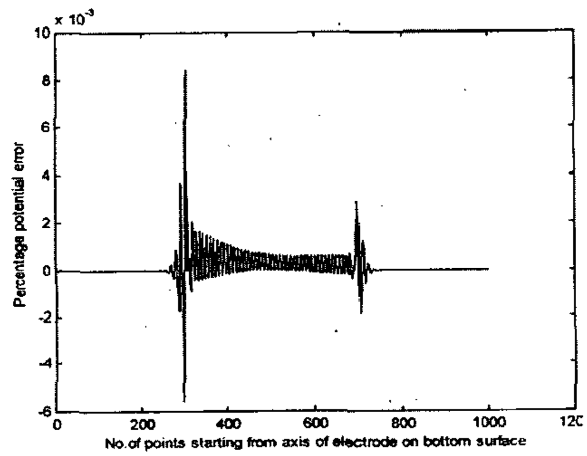

Fig. 1 Variation in potential error on the parallel plane electrode surface.

ELECTRODE CONFIGRATIONS & SIMULATION DETAILS

The Simulated parallel plane electrode is as shown in the figure 2. A total number of 151 ring charges, placed inside the electrode surface are used for simulation. Same number of contour points is placed on the surface of the electrode. Among the contour points corresponding to these charges 50 contour points are placed on the flat-bottom surface of the plane electrode, 51 contour points are placed on the semi-circular surface and 50 contour points are placed on the flat-top portion of the plane electrode. The gap length (h) thickness of the electrode (T), radius of plane portion of the electrode (R_p) and overall radius (R) formed the parameters of numerical experimentation. The overall radius R of the plane profile electrode is $R = R_p + R_e$ and its thickness $T = 2 R_e$.

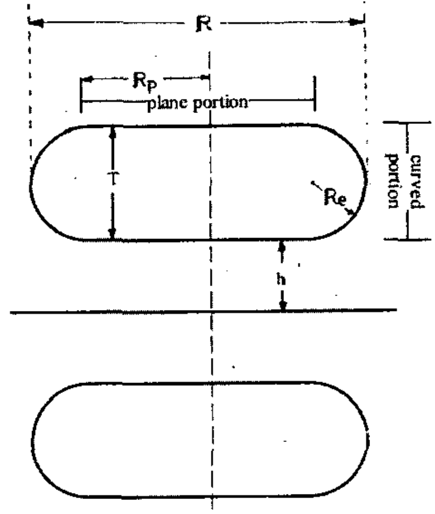

Fig. 2 Parallel plane electrode with its image.

For the Borda's profile X & Y co-ordinates are expressed as

$$X = -2[\sin \Phi - \ln\{\tan((\Phi/2)-(\Pi/4))\}]$$
$$Y = 2[1-\cos \Phi] \qquad (1)$$

with Φ varying from 0 to Π/2 [3]. This results in to a gap separation of Π as X- coordinate tends to infinity. In simulating 3-dimensional Borda's profile, electrode will be symmetrical about the Z-axis if Y-coordinates generated above (using equation 1) is treated as the Z-axis of the cylindrical co-ordinate system. Then X-coordinate will be mapped to r-coordinate of the cylindrical coordinate system. The profile represented by contour points along with the ring charges is as shown in figure 3.

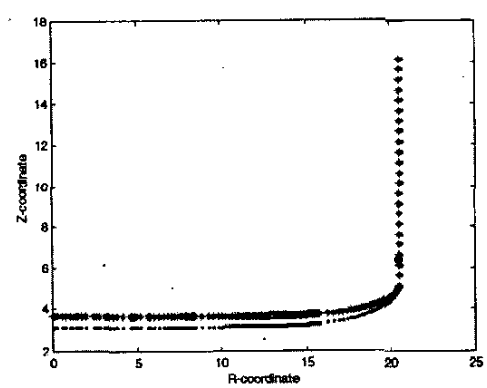

Fig. 3 Borda's profile with vertical cylindrical extension. (Dots are the contour points representing electrode boundary; Stars are the ring charges)

The vertical-cylindrical portion and ring charges are as shown in figure 3. In all 155 ring charges are used to simulate the electrode with equal number of contour points. Out of these, 23 ring-charges and contour points are used to simulate the cylindrical portion (portion other than Borda's profile).

NONUNIFORMITY FACTOR

Nonuniformity factor (f) is defined as the ratio of "maximum-field" in the gap to the "average-field" in the gap.

$$f = E_{max} / (V/h) \qquad (2)$$

where E_{max} = Maximum electric field intensity.
V = Applied potential
h = Gap separation.

This factor is widely referred to, and used in the literature to quantify the nonuniformity of various gaps [7]. For a perfectly uniform field this factor will be unity. If any electrode configuration deviates from the uniform fields (which is generally the case with practical electrode configurations) maximum field generally occurs on the electrode surface. In the present study the maximum electric field occurred at the junction of plane & curved portion for parallel plane electrode (see figure 2). Where as for the Borda's profile maximum electric field occurred at the edge of the Borda's profile (meeting with vertical portion; figure 3).

RESULTS AND DISCUSSION

Parallel plane electrode

Systematic numerical experiments to demonstrate effect of plane radius on field distribution were conducted by changing the plane radius as shown in the figure 4.

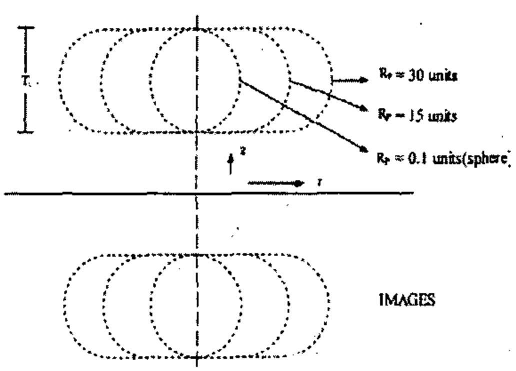

Fig. 4 Parallel plane electrode with different radii.

As plane radius shrinks the gap approaches that of a sphere. This in the process also demonstrates, how nonuniform are the fields due to sphere gaps, which are generally treated as quasi-uniform fields. This is an important result as the sphere gaps are used as standard test gaps in high voltage measurement [8].

These numerical experiments were conducted with gap separation "h"of 15 units and thickness of electrode "T" of 30 units. The electric field intensity distribution is as shown in the figure 5.

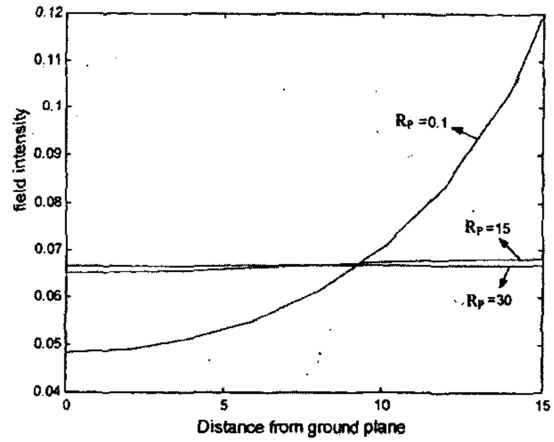

Fig. 5 Variation in field intensity along the axis symmetry with plane radius as parameter. (h=15 units; T=30 units).

It is to be noted that the maximum field on the electrode surface occurred at the edge of plane portion for all the plane radii.

The effect of electrode thickness "T" in relation with the gap separation "h" is varied which indicate that the large the plane electrode thickness more uniform will be field distribution as indicated the figure 6.

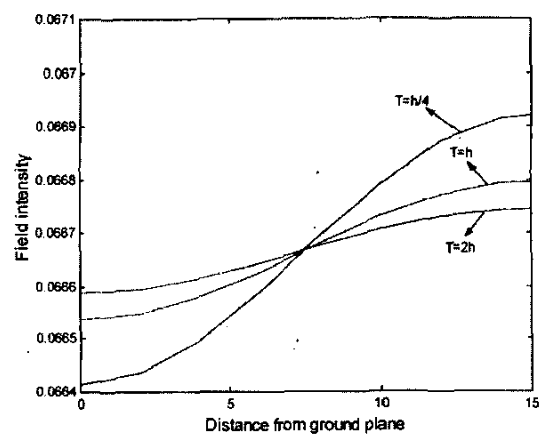

Fig. 6 Variation in field intensity along the axis of symmetry with electrode thickness as parameter. (h=16 units; R_p=30 units)

Comparison with Borda's profile

In order to compare the performance of Borda's profile with parallel plane electrode the overall radiuses of the two electrodes are maintained equal and the gap separation is also maintained same. The field intensity distribution along the gap length at the axis of symmetry is as shown in the figure 7. The plot indicates that the Borda's profile yields more uniform fields compared to parallel plane electrode.

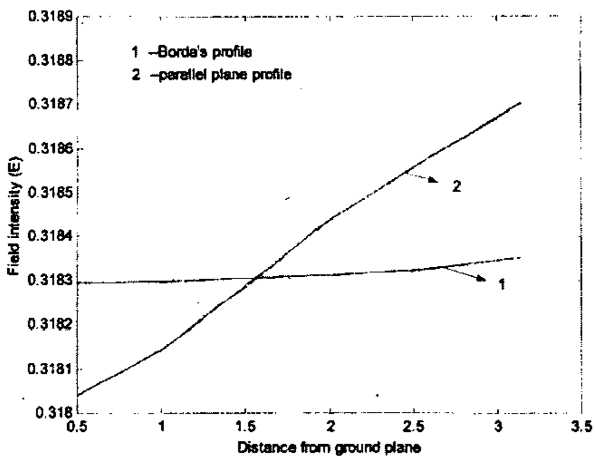

Fig. 7 Variation in electric field intensity along the axis of symmetry. (Overall radius R=20 units; Plane radius R_p=5 units; gap separation h=Π units)

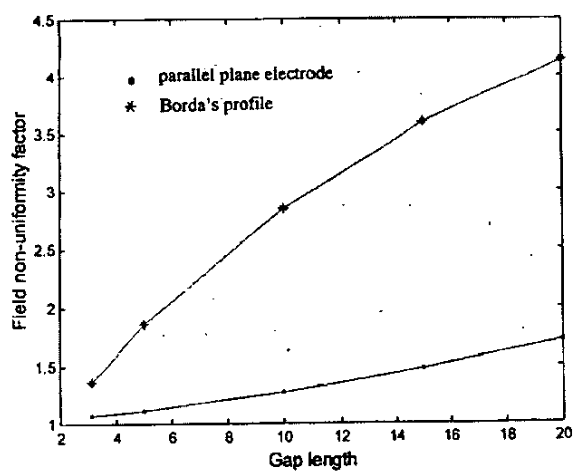

Fig. 8 Variation in electric field intensity along the axis of symmetry. (Overall radius R=20 units; Plane radius R_p=5 units;).

The comparison on the basis of field nonuniformity factor for these electrodes is attempted by varying gap separation "h". It is observed that for all gap separation starting form Π units to 20 units the ratio of highest electric field intensity in the gap to that of average electric stress was lower for the parallel plane electrode. And nonuniformity increases at a faster rate for the Borda's profile compared to the parallel plane electrode as seen form figure 8. The important aspect to be noted is for Borda's profile the maximum electric field occurs at edge of the profile away from the axis.

CONCLUSIONS

- In case of parallel plane electrode large plane radii of the plane electrode results in to uniform fields.
- As electrode thickness of the parallel plane electrode increases, the nonuniformity in the field decreases.
- Borda's profile yields more uniform field in the mid region, towards the gap axis, which is generally, the region of interest.
- On the basis of nonuniformity factor, for the same over all dimensions and gap separation parallel plane electrode appears to be more uniform.
- For Board's profile the loss in uniformity is more with increase in gap separation.

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